APPENDIX C

EVALUATION OF Et-GRASS (Eto)
IN THE DELTA

State of California
The Resources Agency
DEPARTMENT OF WATER RESOURCES
San Joaquin District

EVALUATION OF ET-GRASS (ETo) IN THE DELTA

by

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INTRODUCTION

This evaluation describes efforts to resolve the difference between the recent (1994) estimates of ETo in the Delta developed by Morteza Orang and estimates made by DWR several years ago (1976). George Sato, a retired annuitant with DWR, focused on evaluating Mr. Orang's current procedures and estimates, while Norman MacGillivray, also a retired annuitant with DWR, focused on investigating the validity of the earlier ETo estimates (previously referred to as PET estimates).

The problem arose because of the need for historical Delta ETo values for each month of each year, beginning in 1921. These values were needed by the Delta Modeling Section of DWR's Delta Planning Branch.

Dr. Hossein Ashktorab of DWR's Central District conducted a literature search to select an appropriate method to estimate historical monthly ET. After consulting with Mr. George H. Hargreaves, Research Engineer, Utah State University, and with staff members of U. C. Davis, it was concluded that the Hargreaves-Samani equation would provide the best method. The basic information required by the Hargreaves-Samani equation is monthly mean maximum and minimum air temperatures and extraterrestrial radiation.

In 1992, Dr. Ashktorab and Mr. Sato conducted a search to locate records of minimum and maximum air temperatures in the Delta since 1921. The Lodi and Stockton fire stations on the eastern edge of the Delta were found to have these data.

At about this time, Dr. Ashktorab left DWR and Mr. Orang was hired to continue Dr. Ashktorab's work. The final draft of this report, historical monthly *ETo Estimation in the Delta*, published in 1994, is largely credited to Mr. Orang.

The report describes in detail the process of deriving monthly ETo's for historical periods. It also describes the procedures used to test the validity of the estimated values. The work appears to have been done thoroughly, but the procedures as set forth require further attention. For instance, the Hargreaves-Samani equation does not directly take into account wind and humidity factors, which can significantly influence ETo. This fact may tend to distort ETo values estimated for different Delta locations. A localized windy day at Rio Vista, for example, may affect ETo there but not in the Lodi/Stockton area.

ETo values at the Rio Vista site appear to be influenced greatly by wind. The influence of this site on the average ETo values for the Delta needs to be carefully analyzed. Comparison of monthly ETo values at the Rio Vista and Oakley sites suggests that wind conditions at Rio Vista may be localized much more than indicated by the Thiessen Polygon Method used in this study.

ETo values derived at the Oakley site from measured pan evaporation for the period 1978-1990 averaged 51.9 inches. At Rio Vista, the mean based on measured pan evaporation during 1978-1989 was 58.4 inches. This higher rate was probably due largely to strong winds passing over the vast dryland area commonly referred to as Montezuma Hills.

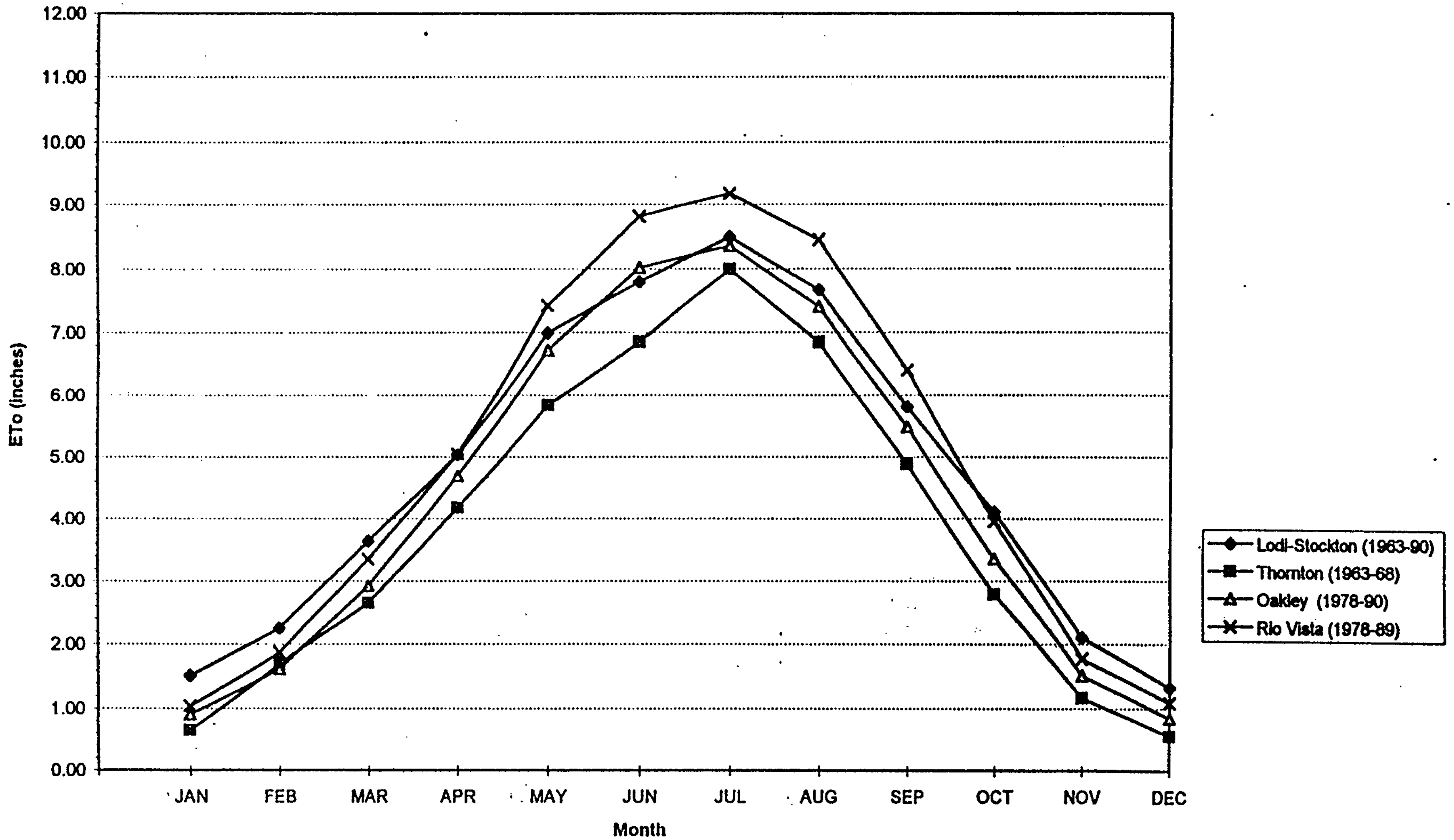
Comparisons of mean ETo values derived from measured evaporation at the Thornton, Oakley, and Rio Vista sites show a high degree of correlation with values estimated with the Hargreaves-Samani equation at the Lodi/Stockton site (Figure 1). However, similar comparisons for specific years show poorer correlation, probably because the Hargreaves-Samani equation is insensitive to climatic factors other than temperature and solar radiation.

Review of Mr. Orang's report by other DWR staff members raised questions concerning the validity of the resulting average Delta ETo values, since mean annual ETo is about 6 inches higher than the average evapotranspiration rate currently used by the Modeling Support Branch. This two-part report summarizes efforts to answer these questions. The first part summarizes the report's major points. The second part presents detailed comments on estimating PET in the Delta.

FIGURE 1

Comparison of Pan ETo at Three Delta Sites and ETo Derived by Hargreaves-Samani Equation for Lodi-Stockton Area

Mean of Values for 1963-1990



MAJOR POINTS

Several major points were identified in the current analysis of (1) development of pa evaporation-based estimates of PET, and (2) recent estimates of ET-grass based on th Hargreaves-Samani equation. The first three points concern the historical development of E estimates. The last seven address the application of the Hargreaves-Samani equation.

- There is a paucity of climatic data for the Delta. Evaporation data collected b D. C. Muckel, Arthur de Rutte, and J. H. Lawrence are believed to be reliable an unbiased, but reflect variations attributable to different pan surroundings. The 198 estimate of PET for the Delta appears to be reasonable. That estimate for a normal yea is about 46.1 inches.

- Maurice Roos points out in his March 22, 1994, memo to Tariq Kadir that he has confidence in the accuracy of the ETo values for the Delta area which resulted from extensive work in 1976. The estimated average for the Delta (Delta lowlands and Delta uplands areas) is 44.5 inches. Subsequently, in 1981, that average ETo value was refined to 46.1 inches. By comparison, ET-grass for the Sacramento and San Joaquin Valleys was estimated to be about 49 inches. Additional pan evaporation data collected since 1976 suggest that the average for the Delta could be somewhat higher. Obtaining a cross-section of the Delta temperature and wind data is necessary to confirm this suggestion.

- Mean annual ETo values measured with a lysimeter at the Thornton-2S site (Delta uplands) during the period 1963-1968 averaged 47 inches, or about 2½ inches above the average value for the Delta lowlands estimated in 1976.

- Mr. Morteza N. Orang derived ETo values from pan evaporation measured at the Oakley site during the period 1978-1990. The estimated ETo was 51.9 inches. At Rio Vista, the mean based on measured pan evaporation during the period 1978-1989 was 58.4 inches. The ETo value at Oakley is comparable to the 49 inches implied above as the values applicable to the eastern fringe of the Delta. The Rio Vista value, at 58.4 inches, is substantially higher compared to the other values mentioned above. The high ETo at Rio Vista is probably due largely to a combination of strong wind and the vast dry land area upwind from the pan. The calculated ETo values at Oakley suggest that the comparatively high ETo at the Rio Vista site is likely to be localized. Delta PET estimates developed in earlier years by J. W. Shannon and by W. O. Pruitt range from 44.3 to 48.8 inches (Table 1).

  It is noted that the average Delta ETo value of 46.1 inches was estimated in 1981 prior to the installation of evaporation pans at the Oakley and Rio Vista sites. But two key questions still remain today: What ETo value is reasonable for the Central Delta? And are multiple values needed to represent the Delta?

- The Hargreaves-Samani equation does not directly take into account real-time wind and humidity factors, which can significantly influence ETo. This fact may tend to distort ETo values resulting from linear regression for different Delta locations. For instance, an increasing ETo at Rio Vista due to a localized windy day will not correspondingly affect ETo in the Lodi/Stockton area. Since the ETo values at the Rio Vista site appear to be influenced greatly by wind, the extent of the influence of this site on the overall ETo values for the Delta should be carefully analyzed. The observation of monthly pan evaporation values at the Rio Vista and Oakley sites suggests that wind conditions at Rio Vista may be localized much more than indicated by the Thiessen Polygon Method.

- The comparisons of mean ETo values calculated from pan evaporation measured at the Thornton, Oakley, and Rio Vista sites show a high degree of correlation with values resulting from the Hargreaves-Samani equation at the Lodi/Stockton site. However, a similar comparison for specific years shows poorer correlation than the mean, probably because the Hargreaves-Samani equation does not account for other climatic factors, such as wind and humidity, that influence evapotranspiration rates.

- To compensate for overestimation of ETo during the winter months by the Hargreaves-Samani equation, Mr. Orang established seasonal co-efficients by combining monthly data into three groups: January through March, April through September, and October through December.

- The linear analysis of ETo's generated by Hargreaves-Samani equations at Lodi/Stockton reflects a warming trend from 1922-1990, possibly because of changing environments at the reading sites. The overall effect is a 1-inch increase in ETo (see attached figures and tables, set 1). However, if the earliest four years (1922-1925) are excluded, the trend is flat.

- Some minor errors were noted in reviewing Mr. Orang's draft report and are noted in the body of this report. The following errors were found; there may be others:

    - Page 132, Table B-1: many of the totals are incorrect.

    - Page 134, Table B-3: totals are incorrect.

    - Page 139, Table C-1: ETo estimate for June 1965 may be too low. Also refer to corresponding temperatures shown in Table A-2.

Principal Recommendations

- Accept an annual value of 46.1 inches for normal year ETo in the Delta.

- Index the resulting values from the Hargreaves-Samani equation at the Lodi/Stockton sit to 46.1 inches (the normal ETo for the Delta) in determining the Delta's historic ET values.

- Acquire by purchase or long-term lease one or two parcels of land to be dedicated tc operation of climate stations. Equip such stations with standard climatological instruments and simple drain-gage lysimeters planted to grass. The importance of consumptive use ir the Delta warrants this extraordinary effort by DWR to collect data there. Long-term stations are difficult to find in the normal course.

COMMENTS ON ESTIMATING
PET IN THE DELTA

Estimates of grass reference crop ET (ETo) have recently been developed for the Sacramento-San Joaquin Delta by Morteza Orang, graduate student at University of California, Davis, and Hossein Ashktorab, Ph.D., both previously with DWR's Central District. Mr. Orang's estimate of annual ETo for the Delta averaged 50.8 inches. This is about 6 inches higher than the estimate of 44.5 inches for Potential ET (PET) made in 1976.

ETo and PET are equivalent terms. Potential ET was defined by H. L. Penman in the late 1940s as the amount of water transpired by a low-growing green crop of about the same color as grass, which completely covers the ground and has an unlimited supply of water and an extensive fetch. ETo has been defined in Mr. Orang's report as having those same attributes.

Crop ET is assumed to be proportional to ETo. Thus, Mr. Orang's estimates will result in increased consumptive use of crops and native vegetation, as well as higher evaporation rates of water surfaces in the Delta. X

The process by which the 1976 ET values were estimated was reviewed and evaluated to further confirm the reasonableness of the ETo values suggested therein. The process is described in the following.

In 1976, estimates were made of crop water use in the Delta as one component of the Central Valley Hydrology Study. Since those estimates were developed various adjustments and refinements have been made, including the ones listed below.

<u>1976</u> *Estimation of Monthly Crop Evapotranspiration for the Central Valley Hydrology Study.* — Appendix A, *Estimation of Evaporative Demand in the Sacramento-San Joaquin River Delta*, memo to James Welsh from Carl Stetson, November 3, 1976. This report describes methods used to estimate normal year (or average) evaporative demand in the Delta. Evaporative demand is evaporation from a class "A" pan located in an irrigated pasture environment. The estimates were based on measurements of dryland pan evaporation in the Delta lowlands adjusted to equivalent pasture pan evaporation, and on measurements of pasture pan evaporation and ET of grass (PET) at one Delta uplands site — Thornton-2S. PET and crop ET were then estimated using crop coefficients (Kp's) from Table 5, Department of Water Resources' Bulletin 113-3, 1975.

<u>1977</u> *The Sacramento Valley Water Use Survey*, June 1977. Appendix *Estimation of Evapotranspiration (ET) for Sacramento Valley and Delta — 1975-76 Dry Year.* John W. Shannon, land and water use consultant, prepared this analysis. The report includes estimates of PET for the 1975-76 year and the average for the previous 10 years. Mr. Shannon calculated monthly ratios of evaporation at Davis 2WSW (a dryland pan site) and Davis Hydromet (a grassed pan site which was equivalent to a pasture pan site). Using those monthly ratios, evaporation from pans located at three dryland sites in the

Delta were adjusted to equivalent pasture pan evaporation. Using coefficients (Kp's) from Department of Water Resources' Bulletin 113-3, monthly estimates of crop ET were then made. Mr. Shannon estimated average year PET in the Delta to be 44.3 inches. Pasture pan evaporation was also estimated for an average year using the Blaney-Criddle equation. Pasture pan evaporation averaged 56.8 inches and PET was 43.7 inches (Table 1).

<u>1978</u> *Sacramento Valley Water Use Survey 1977*, Department of Water Resources' Bulletin 168, October 1978. Appendix *Estimate of Evapotranspiration (ET) for the Delta — 1976-77*. Mr. Shannon expanded his estimates for ET in the Delta to include the 1976-77 year. He used evaporation observed at three locations in the Delta. Using coefficients from Table 19, United Nations Food and Agriculture Organization, Irrigation and Drainage Paper No. 24, to adjust for pan site conditions, Mr. Shannon estimated monthly PET for the Delta to be 47.4 inches for the 1976-77 year. He estimated long-term average PET for the Delta was estimated to be 44.5 inches.

<u>1981</u> Joint DWR and WPRS *Delta Channel Depletion Analysis*. Gordon Lyford (Water and Power Resources Service, now U.S. Bureau of Reclamation), and George Sato and Price Schreiner (DWR) met on several occasions to reconcile differences in crop ET for the Delta as estimated by DWR and by WRPS. The 1976 DWR estimates were compared to estimates made by the U.S. Bureau of Reclamation in October 1978. The USBR estimates were calculated using the Jensen-Haise equation. The analysts used solar radiation data from U. C. Davis (1968-1978) and air temperatures from Brannan Island (1968-1978). Analysts found that "...the values that DWR and WPRS calculated for crop ET's in the Delta had fairly close agreement, therefore, identical monthly ET values were agreed upon for this study." PET or ET of pasture was not shown in this analysis; however, based on the monthly ET's for alfalfa which are listed, PET was calculated to be 46.1 inches for 1976. The relationship between monthly ET of alfalfa and pasture (PET) was determined from crop coefficients listed in Table 5, Department of Water Resources' Bulletin 113-3.

<u>1985-86</u> *Letter from W. O. Pruitt, U. C. Davis, to Marcia Steinberg, DWR staff counsel*. Mr. Pruitt was engaged as a consultant to DWR's legal staff to evaluate the validity of ET for Delta crops as determined by Mr. Shannon for Department of Water Resources' Bulletin 168. Tabulations prepared by Mr Pruitt dated April 23, 1986, show ETo (ET grass) estimated by two methods: (1) observed dryland pan evaporation at one Delta location (Brannan Island) and the relationship between measured ETo and evaporation from a dryland pan at Davis, and (2) measured ETo Davis multiplied by ratios between ETo at Davis and Thornton and multiplied by ratios of evaporation between those same two locations. Mr. Pruitt's estimates of ETo for 1976-77 ranged from 45.7 inches to 49.5 inches, with an average of 47.6 inches. Evaporation rates generally ran about 2 percent or so higher than normal in 1976-77. Thus, adjusting the average of Mr. Pruitt's estimates to a normal year value would put ETo on the order of 46.6 inches. Mr. Pruitt

also referenced his ETo maps, which show normal year ETo of 48.8 inches for the Delta area (Table 1).

1994 Morteza Orang and Hossein Ashktorab prepared a draft report, *Historical Monthly ETo Estimation in the Delta*, published in February. These investigators estimated ETo for the Delta using the Hargreaves-Samani equation. That equation is based on air temperature and solar radiation data, the same inputs used for the Blaney-Criddle equation. Thus, the Hargreaves-Samani equation is perhaps more properly identified as a modified Blaney-Criddle equation. ETo for the Delta was estimated to be 50.8 inches (Table E-1). The stated reason for using the Hargreaves-Samani equation was to estimate historical year-by-year ETo for earlier years for which air temperatures are the only climatic data available. Radiation was calculated from extraterrestrial radiation and temperature data.

Table 1 lists various recent estimates of annual ETo/PET. Some estimates were calculated for a specific year and adjusted to normal year ET, using ratios of evaporation for the specific year to the evaporation for a normal year.

Included in Table 1 is the average annual measured PET at the Thornton-2S site (1963-1968). This value was determined from lysimeter records collected by J. H. Lawrence of DWR. All data collected at this location have been assumed to be correct and valid. This applies to PET, evaporation, and other climate data -- including air temperature, radiation, and atmometer evaporation. It is believed wind movement was not measured.

The ET-grass data shown in Table 1 were estimated by various methods. The estimates made by Mr. Orang, using the Hargreaves-Sumani equation (Orang Table E-1), are the highest of the several estimates shown in Table 1 and are slightly higher than previous estimates of PET for the Sacramento and San Joaquin Valleys. The high estimates result in part from using the Thiessen Polygon method for estimating mean ETo value for the Delta.

DWR estimates of crop ET for agricultural areas throughout the State have, since the late 1950s, been based on measured rates of evaporation from class "A" pans located in irrigated pasture or equivalent environments. To be consistent, that method should also be used in the Delta. However, there are few historical records of pasture pan evaporation in the Delta. Therefore, available data from dryland pans were used but were first adjusted to equivalent pasture pan evaporation. The estimated pasture pan data then provided the basis for estimating crop ET. Crop coefficients relating crop ET to pasture pan evaporation (Kp) were taken from Table 5, Department of Water Resources' Bulletin 113-3. For the present evaluation, only PET (ET-grass) was estimated. Reference crop ET (ET-grass or ET-alfalfa) is now often used as a base from which crop ET's are estimated. The Hargreaves-Samani equation is important from the standpoint of providing such a base. Errors in the estimating base, either evaporation or reference crop, are reflected in the ultimate estimate of crop ET.

The approach used to evaluate the validity of the Hargreaves-Samani equation was to compare ETo estimated using that equation to ET-grass estimated by other methods. A substantial effort was directed toward checking the validity of previous estimates.

TABLE 1

ESTIMATED ET-GRASS (ETo) IN THE DELTA
ANNUAL RATE
(inches)

Source	Estimated Normal Year			Estimated 1975-76 Year	Estimated 1976-77 Year	
	Lowlands	Uplands	Delta	Delta	Lowlands	Delta
DWR 1963-68, J. H. Lawrence		47.1[1]				
DWR 1976, N. MacGillivray	43.3	45.6	44.5			
DWR 1977, J. W. Shannon			44.3	44.2		
DWR 1978, J. W. Shannon			44.5			47.4
DWR-WRPS 1981, G. Sato, DWR P. Schreiner, DWR G. Lyford, WRPS			46.1			
UC Davis 1985-86, W. O. Pruitt	46.7[2]				47.6[3]	
UC Davis 1986, W. O. Pruitt			48.8[4]			
UC Davis/DWR 1994, M. N. Orang, UCD H. Ashktorab, DWR			50.4[5]			

[1]Measured with lysimeter at Thornton-2S.
[2]ETo calculated for 1976-77 adjusted to normal year by ratios of evaporation.
[3]Average of ETo estimated by two methods — (49.5 + 45.7)/2.
[4]Interpolated by W. O. Pruitt from his ETo maps.
[5]Mean shown in Orang's Table E-2.

In 1976, ET-grass was estimated by three different methods; two of those methods firs estimated pasture pan evaporation. ET-grass was then estimated from that evaporation bas using monthly coefficients listed in Department of Water Resources' Bulletin 113-3. A thir method estimated monthly ET directly from dryland pan evaporation.

1. Dryland pan evaporation was adjusted to equivalent pasture pan evaporatio using monthly ratios of pasture pan and dryland pan evaporation observe at the University of California, Davis.

2. Pasture pan evaporation was estimated with the Blaney-Criddle equation which uses air temperature and an index of incoming solar radiation Monthly coefficients were developed from evaporation measured at severa DWR agroclimatic stations in the San Joaquin Valley.

3. ET-grass was estimated from dryland pan evaporation using adjustments presented in the United Nations Food and Agricultural Organization Irrigation and Drainage Paper No. 24.

Two estimates (Methods 1 and 3) were based on evaporation data collected at several dryland evaporation pan sites in the Delta. Several of those pans were installed as part of the U.S. Department of Agriculture-Agricultural Research Service's *San Francisco Bay Investigation.* This work was done in the mid-1950's by Dean C. Muckel, an experienced and able investigator. Other evaporation pans were installed and operated by another competent field expert, Arthur de Rutte, as part of DWR's *Delta Seepage Study* in the early 1960's. Mr. De Rutte's pans were also located at dryland sites. The importance of pan surroundings on evaporation rates was just being recognized at this time; thus, the dryland pan sites selected by Mr. Muckel and Mr. De Rutte were adequate by all standards accepted at that time. Pans were typically located atop levees, in the odd field corner or near pump houses, where they did not interfere with farming operations. Both Mr. Muckel and Mr. De Rutte collected data that are accepted as correct and unbiased. However, for Method 1, the observed evaporation from those dryland sites needed to be adjusted to reflect equivalent evaporation from pasture pan locations. This adjustment was necessary because in ET studies conducted by DWR, pasture pan evaporation is used as the reference for estimating crop ET values.

The procedure for estimating ETo values for the Delta first required the short-term evaporation records for the Delta locations be extrapolated to long-term using evaporation records for Davis 2WSW (a dryland site) as the basis. Fortunately, there is a long record for the Davis 2WSW station. That record begins in 1926 and is continuous to the present. Monthly ratios of evaporation at Davis 2WSW (dryland site) and the nearby Davis Hydromet (pasture site) were calculated for the period 1959 to 1972. Those ratios were then used to estimate pasture pan evaporation from the long-term evaporation at dryland sites in the Delta. That estimate was 56.5 inches for a normal year in the Delta lowlands.

An error was made in the above procedure. Mr. Pruitt later pointed out that, although the station name remained the same, the Davis 2WSW was, in fact, moved to a new site in 1965. For the 10-year period preceding the station relocation (1955-1964), annual evaporation averaged 70.9 inches. The average annual evaporation for the 10 years following the move averaged 84.7 inches. This 20-percent difference is probably attributable to increased evaporation caused by the change in pan surrounding. Examination of the evaporation record for Davis-Hydromet supports this conclusion. Annual evaporation at Davis-Hydromet for 1965-1970 averaged 2½ percent less than the average for 1959-1964. The substantial difference in evaporation resulting from moving the Davis 2WSW pan only a relatively short distance demonstrates the remarkable influence of pan surroundings. More importantly, the difference in evaporation rates between dryland sites negates the validity of using ratios determined at one location to adjust dryland to equivalent pasture pan evaporation at another location.

A second estimate of pasture pan evaporation for the Delta was made using the Blaney-Cridd equation (this was Method 2). Air temperatures measured in the Delta were used with month "K's" derived from evaporation pans in the San Joaquin Valley. The annual rate of pastu pan evaporation in the Delta lowlands estimated by this method was 55.2 inches.

Monthly PET was estimated from those evaporation rates using monthly Kp's from Table Department of Water Resources' Bulletin 113-3, 1975. Normal year PET was estimated to t 43.4 inches for the evaporation ratio method (Method 1) and 42.8 inches for the Blaney-Criddl method (Method 2). A third estimate of monthly PET was made using the observed drylan pan evaporation together with adjustments for wind movement, relative humidity, and th extent of upwind fetch of dryland. These adjustments were taken from Table 19, Unite Nations Food and Agriculture Organization Paper No. 24. PET was estimated to b 43.8 inches.

The three estimates of PET were in remarkably good agreement. Monthly and annual rates o PET are listed in Table 2.

For the current analysis the same methods were used, but not the same dryland stations. Also the extrapolation to long-term evaporation rates considered the difference in evaporation resulting from station relocation for U. C. Davis 2WSW, as pointed out by Mr. Pruitt.

In the late 1970s, the Central District installed additional evaporation pans in the Delta as shown below.

Station	Period of Record
Oakley 1NE	8/77-3/92
Rio Vista 5S	7/77-6/89
Thornton 5S	9/77-5/80
Thornton White Slough	6/80-11/83

Data from two of these stations (Oakley and Rio Vista) and from J. H Lawrence's Thornton-2S site (1963-1968) were used by Mr. Orang in his work. Annual evaporation varied markedly between locations as follows:

Orang's Table	Location	Record	Annual Evaporation Inches	Percent of Average
B-2	Oakley 1SE	1978-1990	66.27	99
B-3	Rio Vista	1978-1989	75.48*	113
B-1	Thornton-2S	1963-1968	59.26*	88

*The total in Mr. Orang's Table B-3 was incorrectly shown as 58.42 inches and Table B-1 was 51.44 inches.

TABLE 2

ESTIMATED MONTHLY POTENTIAL EVAPOTRANSPIRATION (PET) IN THE SACRAMENTO-SAN JOAQUIN RIVER DELTA[1] FOR NORMAL YEAR

Month	Estimates Based on Equivalent Pasture Pan Evaporation[2]		Estimates Based on Dryland Pan Evaporation, United Nations-Food and Agriculture Organization[3]
	Blaney-Criddle Method	Pasture/Dryland Ratio Method	
	Potential ET — Inches		
January	0.8	0.8	0.6
February	1.3	1.2	1.0
March	2.3	2.7	2.5
April	3.6	4.0	3.8
May	5.3	5.2	5.2
June	6.7	6.0	6.2
July	7.7	7.2	7.5
August	6.4	6.5	6.8
September	4.3	4.5	4.8
October	2.7	3.0	3.2
November	1.3	1.6	1.6
December	0.4	0.7	0.6
March to October	39.0	39.1	40.0
Annual Total	42.8	43.4	43.8

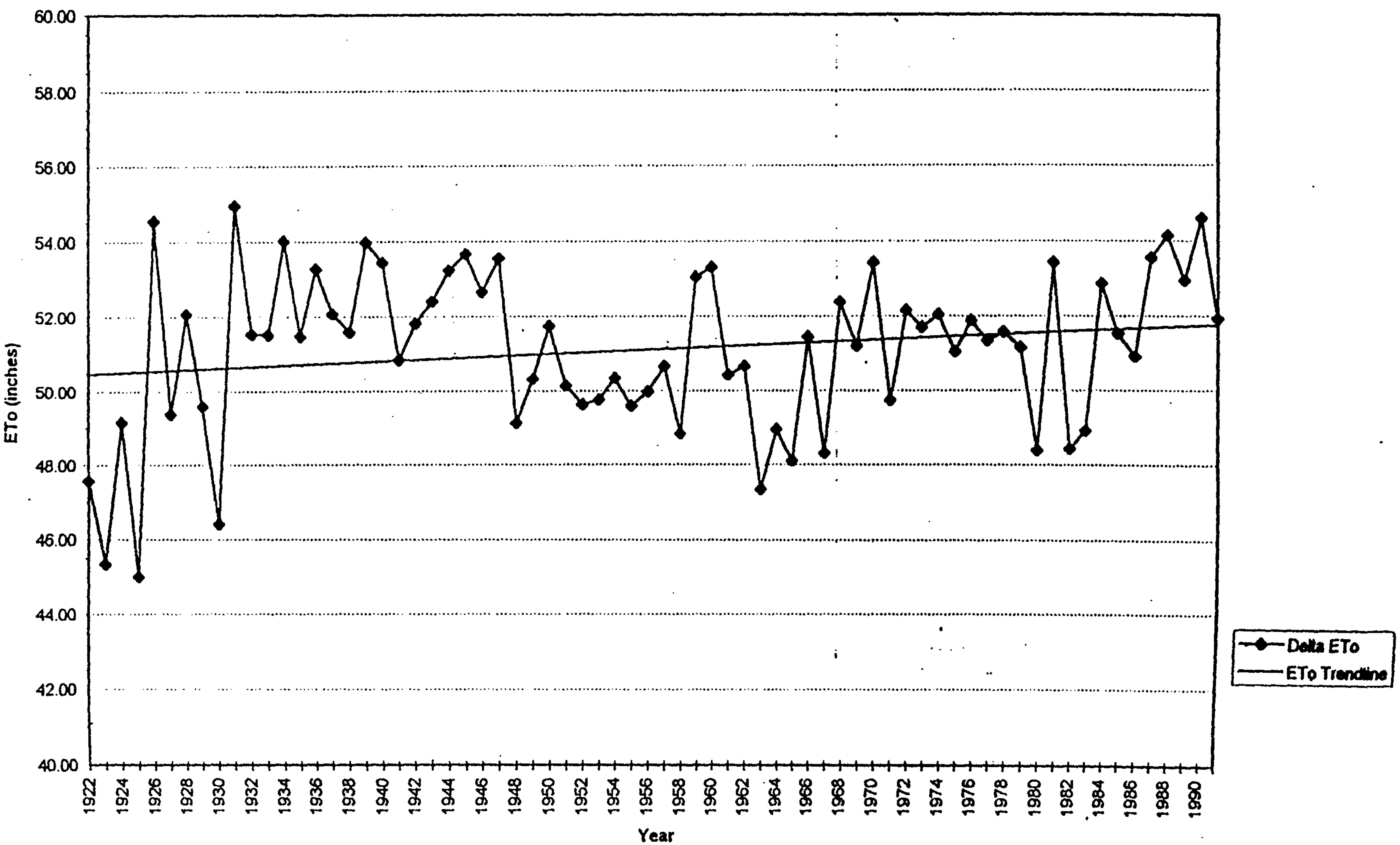
[1]Estimates for the Delta lowlands.
[2]Estimates based upon the monthly ratios of PET to evaporation shown in Table 5, Bulletin 113-3.
[3]Based upon method described in United Nations-Food and Agriculture Organization Irrigation and Drainage Paper No. 24, *Crop Water Requirements*.

Mr. Orang's Hargreaves-Samani estimate of average ETo for Lodi is 56.9 inches (his Table C-1). PET for San Joaquin and Sacramento Valleys is about 49 inches. This estimate for Lodi is about 16-percent higher than for the valley areas. Mr. Orang also estimated ETo at Stockton as 56.8 inches.

Annual ETo for the Delta estimated with the Hargreaves-Samani equation increases about 1 inch from 1922 to 1990. This trend is shown in Figure 2.

FIGURE 2

Delta ETo Data - Yearly Totals for 1922-91



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There is much variation in measured evaporation rates for the many pan locations in the Delta. Much of this variation is believed to be attributable to the pan surroundings. The difficulty in locating good pan sites is understandable in the absence of acceptable grower-owned sites. It is recommended that DWR rent or purchase one or two small plots of land and plant them to pasture grasses to provide proper pan environments. The San Joaquin District has acquired a 10-acre parcel on the Kern Water Bank property for that purpose. The value of climate data which would be collected at such sites is certainly worth the dollar cost.

Some minor errors were noted in reviewing the draft report and are noted in the following:

- Page 132, Table B-1: many of the totals are incorrect
- Page 134, Table B-3: totals are incorrect
- Page 139, Table C-1: ETo estimate for June 1965 may be too low. Also refer to corresponding temperatures shown in Table A-2.

RECOMMENDATIONS

- After an in-depth review of all pertinent ETo and related studies previously conducted b DWR and others, it is recommended that 46.1 inches be adopted as an average norma year ETo value for the Delta. It should also be noted that the mean ETo value calculate from pan evaporation data collected at the Thornton-2S site (Delta uplands) from 196. through 1968 is 47 inches.

- The modified Hargreaves-Samani equation adjusted for normal year ETo (46.1 inches), is a reasonable method for estimating long-term historical ETo in the Delta.

- The air temperature data collected at Stockton and Lodi fire stations should be the primary base for using the Hargreaves-Samani equation.

- The importance of consumptive use in the Delta warrants an extraordinary effort to collect data there. Long-term stations are difficult to find in the normal course. Therefore, it is recommended that DWR acquire, by purchase or long-term lease, one or two parcels of land to be dedicated to operation of climate stations in the Delta. It is suggested that those stations be equipped with standard climatological instruments and include simple drain-gage lysimeters planted to grass.

- To compensate for overestimation of ETo during the winter months by the Hargreaves-Samani equation, Mr. Orang developed seasonal co-efficients by combining monthly data into three groups: January through March, April through September, and October through December. It is suggested that the number of subsets thus established by Mr. Orang be increased. The primary advantages may be an improved correlation between ETo values derived from pan evaporation and the corresponding ETo values estimated from the Hargreaves-Samani equation, and the ability to identify any existing anomaly requiring further attention.